Predictability Limitations of Long-Range Sound Propagation

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LONG-TERM GOAL

Our long-term scientific goal is to understand the basic physics of low-frequency long-range sound propagation in the ocean, and the effects of environmental variability on signal stability and coherence. We seek to understand the fundamental limits to signal processing imposed by ocean variability to enable advanced signal processing techniques, including matched field processing and other adaptive array processing methods.

OBJECTIVES

The principal objective of our ongoing effort is to develop a theory of acoustic fluctuations in long-range propagation that correctly accounts for measurements. This objective is motivated by the failure (as reported by Colosi *et al*, 1999) of traditional approaches (see, e.g., Flatté *et al*., 1979) to the study of wave propagation in random media (WPRM) to predict measured time spreads and intensity statistics in recent long-range underwater acoustic experiments. Work to date strongly suggests that acoustic fluctuations are to a surprisingly large degree controlled by a property (the ray-based stability parameter α or the asymptotically equivalent mode-based waveguide invariant β) of the background sound speed profile, rather than details of the sound speed perturbation. As a result, much of the recent theoretical work has been motivated by a desire to understand what wavefield properties are controlled by α or β.

APPROACH

The group in Miami (M Brown, F J Beron-Vera, I Udovydchenkov and I Rypina) has employed a combination of ray- and mode-based theory, combined with PE simulations, to study and quantify acoustic fluctuations. Much, but not all, of the mode-based theory is based on an asymptotic analysis, as this provides a direct link to the ray-based analysis. Similarly, much, but not all, of the ray-based analysis makes use of action-angle variables, as this provides a direct link to the mode-based analysis. Another crucial connection between the ray- and mode-based analyses derives from the asymptotic equivalence of the ray stability parameter α and the mode waveguide invariant β. In recent years we have focused on explaining features of measurements made during the Slice89 and AET propagation experiments. (In the coming years our observational focus will shift to the SPICE04 and LOAPEX

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14. ABSTRACT
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data sets.) Specific topics/questions, which have been investigated by the PI during the past funding cycle, are listed in the following section.

WORK COMPLETED

1. Travel time stability

As an extension of earlier work (Beron-Vera and Brown, 2003) which showed that ray stability is controlled by α, it was recently shown that travel time stability is also controlled by α (Beron-Vera and Brown, 2004). Specifically, three different measures of time spreads were shown to be controlled by α. Because α controls both ray amplitudes and phases, wavefield intensity statistics should also be controlled by this property. Current work is focused on quantifying this connection.

2. Ray-mode duality

It has been shown (Brown *et al.,* 2004) that the ray-based stability parameter α is asymptotically equivalent to the mode-based waveguide invariant β. Further, in the same paper it is shown that a remarkable number of properties of wavefields and their stability are controlled by this parameter.

3. A simple transformation eliminates PE errors

A simple transformation has been discovered (Rypina *et al.,* 2004) which allows solutions to the Helmholtz equation to be generated by solving (in the transformed environment) the parabolic wave equation. There are several caveats which will not be discussed here; in spite of these caveats, the result is somewhat surprising and extremely useful.

4. Modal group time spreads

It has recently been shown (Udovydchenkov and Brown) that modal group time spreads are controlled by β. This work is currently being written up.

5. Beam dynamics

The dynamics of directionally narrow acoustic beams have recently investigated by Beron-Vera and Brown. Both the spatial and temporal spreading narrow beams have been shown to be controlled by α (or its mode equivalent β). This conclusion is supported by both ray- and mode-based analyses. This work is currently being written up.

6. *Fresnel zones in inhomogeneous media*

Fresnel zone widths for both rays and modes have recently been investigated by Brown, Udovydchenkov and Rypina (see also Virovlyansky et al., 1997). It has been shown that in a stratified environment both ray and mode Fresnel zone widths are controlled by α. This work is currently being written up.

RESULTS

Although our goal of developing a theory of acoustic fluctuations in long-range propagation has not yet been achieved, significant progress has been made. The forward scattering physics are much better understood than was the case a year or two ago. An important result of the PI's work over the past few years is conceptual: the forward scattering of sound — by internal-wave-induced perturbations, for example — is largely controlled the background sound speed structure, Thus, sound scattering in environments with identical internal-wave-induced sound speed perturbations but different background speed structures may be completely different.

IMPACT/APPLICATION

Our work is contributing to an improved understanding of the basic physics of low-frequency long-range sound propagation in the ocean, and the associated loss of signal stability and coherence imposed by environmental variability. This knowledge contributes to an understanding of the limitations of advanced signal processing techniques, such as matched field processing.

TRANSITIONS

Our results are being used to interpret (reinterpret, in some cases) data collected in long-range propagation experiments, e.g. SLICE89, AET, SPICE04 and LOAPEX. We are unaware of transitions to system applications.

RELATED PROJECTS

The PI and collaborators listed above actively collaborate with the NPAL (North Pacific Acoustic Laboratory) groups at SIO (P. Worcester, W. Munk, B. Cornuelle, M. Dzieciuch), APL/UW (R. Spindel, B. Dushaw, B. Howe, J. Mercer, R. Andrew, F. Henyey and M. Wolfson) and NPS (J. Colosi).

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